The Origins Billion Star Survey

A Feasibility Study

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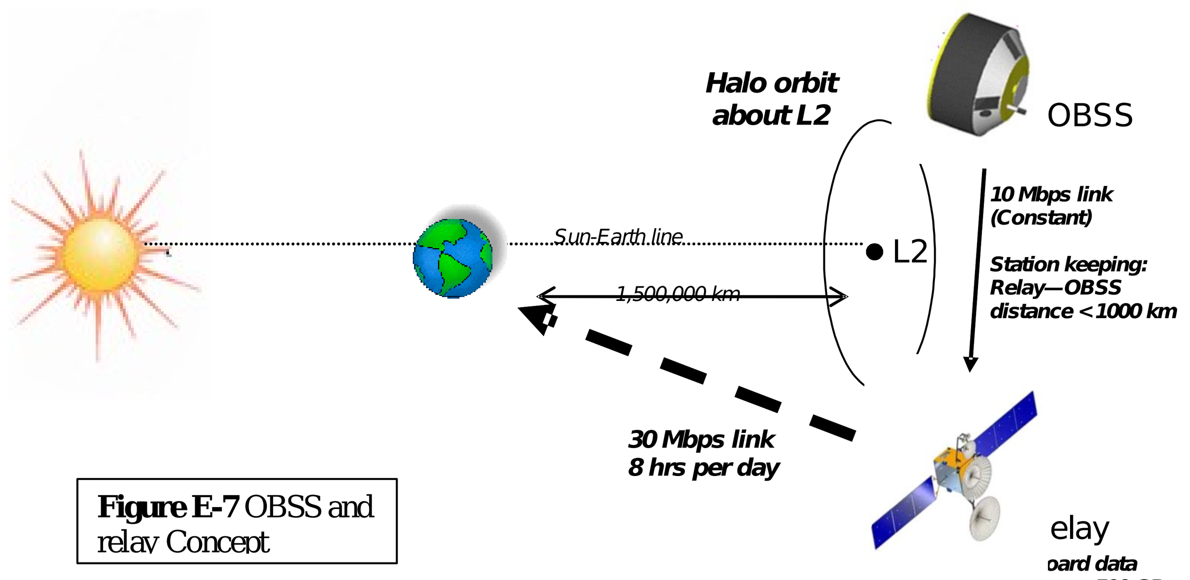


Figure E-7 OBSS and relay Concept

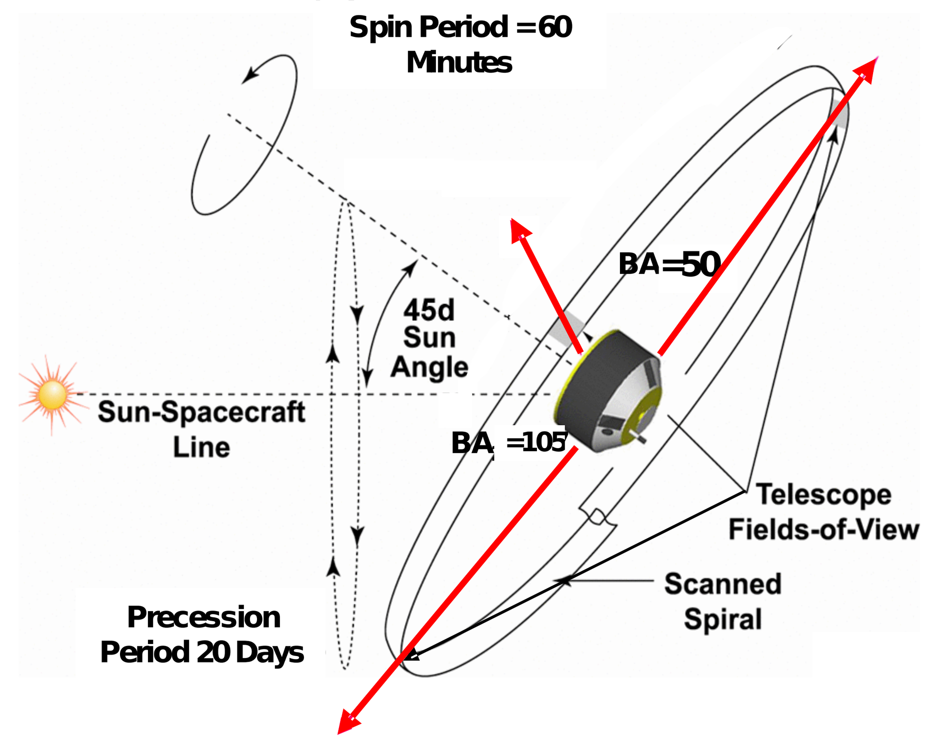
DESCRIPTION

- The OBSS satellite will be positioned at L2. It will spin once about the spin axis every hour, which, in turn, will precess about the Sun-Spacecraft line with a period of 20 days. The resultant scanning law results in 70% sky coverage every 20 days The mission length of five years will result in an average of 127 measurement epochs of each star, and an average of 6600 observations per star.
- The OBSS instrument is a three-aperture, high-precision, Three Mirror Anastigmat telescope with a focal length of 45 m, field of view of 1.0 x 1.0 deg, and a focal plane consisting of 290 CCDs. The instrument takes astrometric, wide band, and spectroscopic (dispersed) measurements.

OBJECTIVE

The OBSS is an all-sky astrometric, photometric and spectroscopic survey of unprecedented size and accuracy, providing comprehensive characterization of stars in a volume that encompasses half the Galaxy.

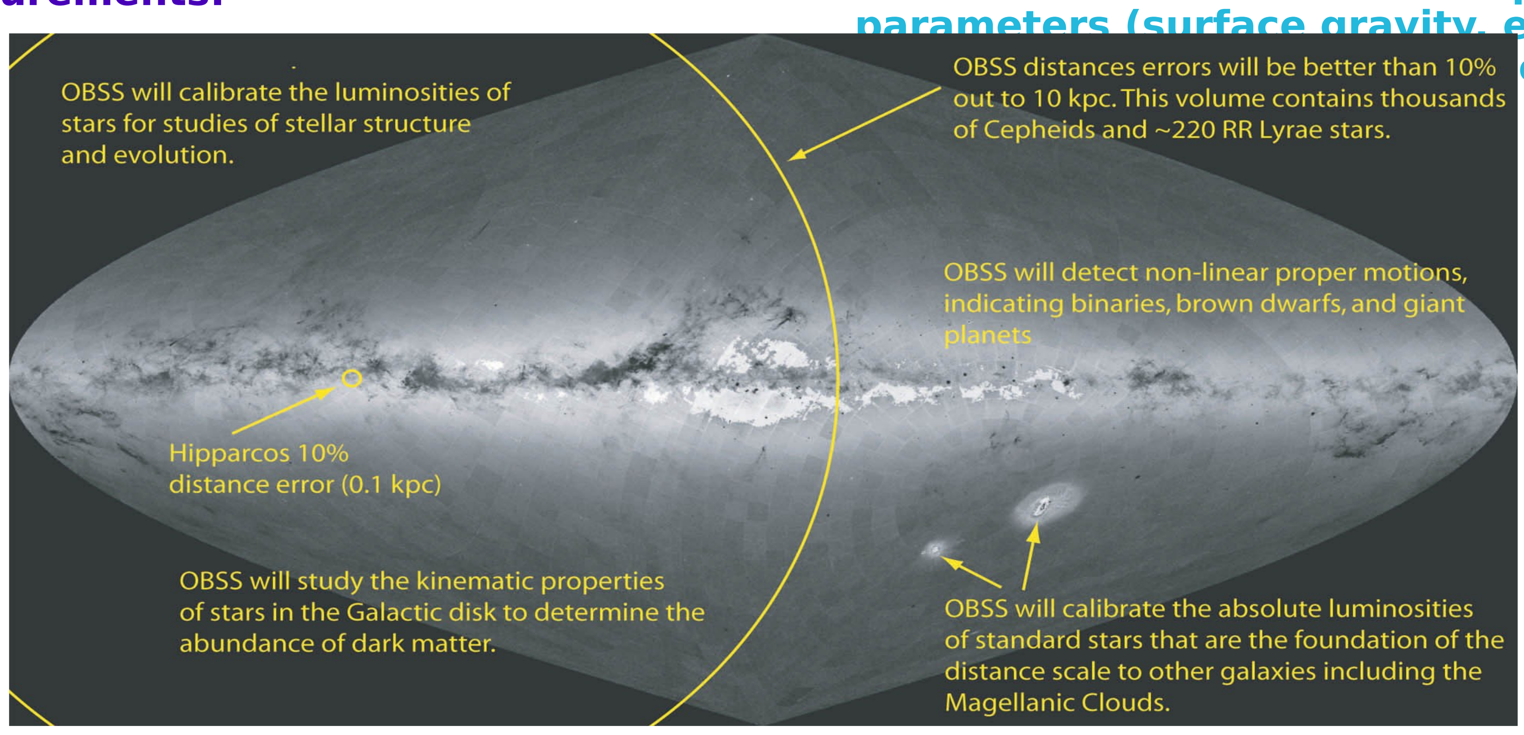
- Full catalog of one billion stars complete to m_v=20
- Astrometric mission accuracy (position, proper motion, parallax) of brighter stars (7 < m_v < 14) to < 10 μas / μas yr⁻¹/ μas
- Astrometric mission accuracy of fainter stars (14 < m_v < 20) degrades as per photon statistics, with mission accuracy ~100 μas for m_v = 20
- Photometric accuracy ~ 1 millimag @ m_v = 14
- Spectroscopic system provides determination of stellar astrophysical parameters (surface gravity, effective temperature, metallicity, extinction)



Scan Geometry

Stellar Luminosities and Ages

- OBSS will determine distances and luminosities to 1% for 2x10⁶ G,K, and M dwarfs, 1x10⁶ F dwarfs, 100000 A dwarfs, and 10,000 B dwarfs.
- 30,000 of these will be detached eclipsing binaries, for which we can measure ALL important physical parameters, and hence their ages. These stars will enable the calibration of stellar atmospheric and interior models over the whole range of spectral types.
- A 1% distance error corresponds to a 167 Myr age uncertainty for a single star. By binning and averaging we will be able to resolve distinct age groups in the disk to 8 Myr, and in the halo to 20 Myr.
- Using the OBSS model calibration, we can obtain ages to ~20% for all other stars.
- OBSS will measure accurate distances for individual stars in star formation regions (Taurus-Auriga, Orion) too faint to be observed by Hipparcos.
- OBSS will provide calibrate the absolute luminosities of "standard candles" such as Cepheids and RR Lyrae stars.



Galactic Structure and Dynamics

OBSS will have a profound impact on our ideas of the formation and buildup of the Milky Way and other Local Group galaxies.

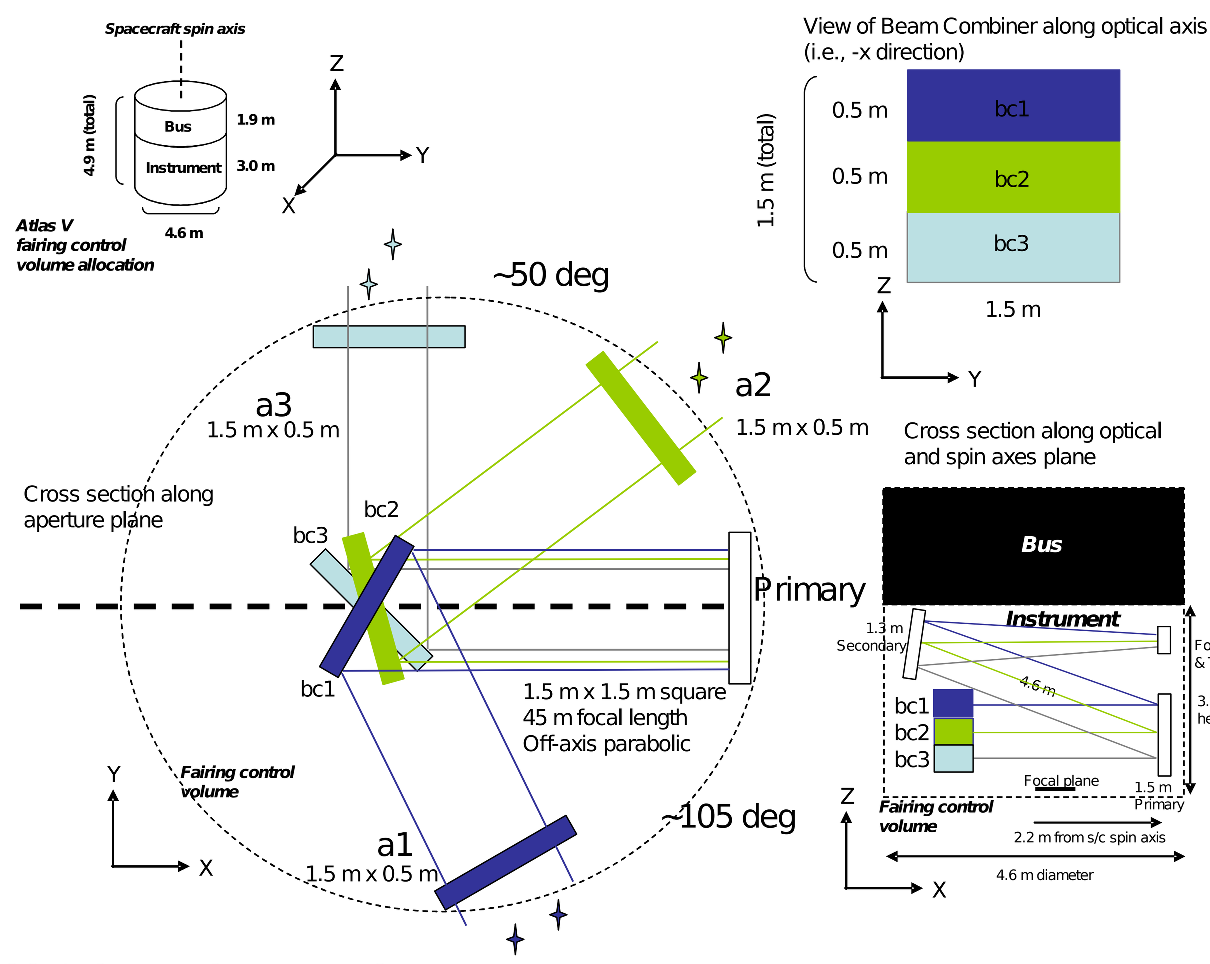
Measuring positions, distances, and velocities of stars in known tidal streams (eg. Sagittarius dwarf, Palomar 5) will enable measurement of the Galactic potential to an accuracy approaching 1%.

Using the same data will enable:

- a phase space search for additional tidal streams and remnants.
- measurement of the distance to the Galactic center
- measurement of the Galactic rotation curve
- proper motions (orbits) of M31, the Magellanic Clouds, and several other Local Group dwarf galaxies
- internal kinematics in the Magellanic Clouds and other Local Group dwarf galaxies
- kinematics and ages of young stars in star formation regions

Solar System Studies

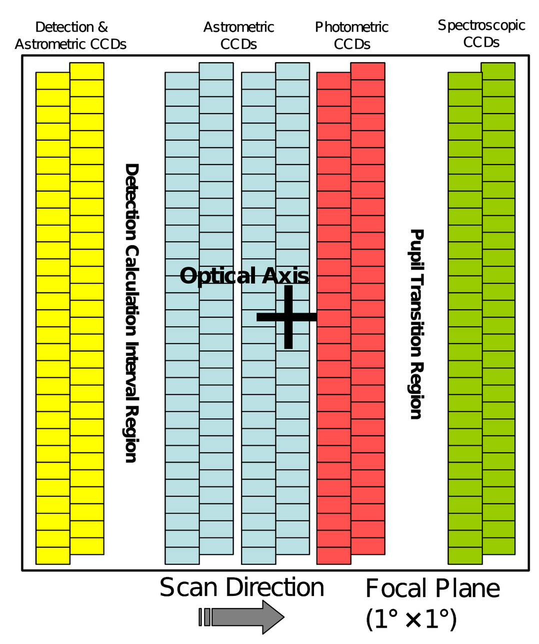
- OBSS will detect >80% of near Earth asteroids with r > 140 m
- Warning efficiency of >90% for hazardous objects of this size or larger
- OBSS will detect hundreds of new Kuiper Belt and trans-Neptunian objects.



OBSS-A Optics Concept. Shown are: (upper left) spacecraft volume assuming Atlas-V 5m short fairing, along with reference coordinate axes; (lower left) Cross section of the aperture plane. Light entering an aperture (a1, a2, a3) hits a "beam combiner" mirror (bc1, bc2, bc3) and is directed along the optical axis to the primary. (Lower right) The off-axis primary directs the combined light to a secondary above bc1, which directs the beam to a the tertiary and a series of fold flats. The final fold flat directs the beam onto the focal plane, which lies below the aperture plane. (Upper right) View of the beam combiner mirrors.

Instrument

- 1.5x1.5m square off-axis primary
- 10-15 optical surfaces, for optical throughput of 40-60% over 300-1000nm bandpass
- Reflection grating with spectral resolution R = 3000, and 15nm range centered on MgB @ 510nm
- 174 astrometry CCDs, 58 photometry CCDs, and 58 spectroscopy CCDs.
- Each CCD uses 4096x670, 13.5μm x 40.5μm rectangular pixels to reduce clocking rate and readout noise.
- 8 photometric filters
- Data rate =10 Mbps continuous



OBSS Focal Plane

Giant Planets and Brown Dwarfs

From Astrometric Wobbles:

For circular orbits at arbitrary inclination, the average semi-major must exceed:

$$a_{\Box} \sim 47.6 \text{ x } 1/d_a \text{ x } (T_{C,yr} / M_{TOT,S})^{2/3} \text{ x } M_{Planet,J} \text{ x } 1/s_{p,10}$$

[in units of s]

$$d_a \sim 23.8 \text{ x } 1/N_{s,2} \text{ x } (T_{C,yr} / M_{TOT,S})^{2/3} \text{ x } M_{Planet,J} \text{ x } 1/s_{p,10}$$

[pc]

with: d_a the distance to the star in pc, $T_{C,yr}$ the period of the planet/brown dwarf companion in years, $M_{TOT,S}$ the mass of the system in units of solar masses, $M_{Planet,J}$ the mass of the planet in Jovian masses, $s_{p,100}$ the mission-end parallax accuracy in units of 10 mas, and $N_{s,2}$ the desired cutoff criterion in units of 2s. We have used an average projection factor of 0.476 to account for inclination effects.

Non-linear motion can be detected if the period of the companion is of order of the mission duration (TM) or less. From Kaplan & Makarov 2003 [AN, 324,5, 419]), we derive an upper limit to the distance:

d_{lim} ~ 36.9 x (TM,yr)2 x (TC,yr)-4/3 x (MTOT,S)1/3 x 1/ [N□,2 x sp,10] [pc]

For a 'Sun-Jupiter' system, the 95% distance limits are $d_a \sim d_{lim} \sim$ 93/124/186 pc for 100/50/25% of the sky.

Conservative detection thresholds yield ~9,500 extrasolar giant planets in the OBSS catalog, of which 7,500 will yield orbit solutions.

From Transit Photometry:

The OBSS scanning law has excellent temporal coverage, with:

- 3 Apertures imaged simultaneously on a ~ 1x1° Focal Plane
- 3 Focal Plane Transits (FPT) per 60 min Spin Period
- 3 Detections per FPT
- 6600 observations per star on average over 5 years